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THE MEASUREMENT OF SENSORY THRESHOLDS IN EXCEPTIONAL CHILDREN, AN EXPERIMENTAL APPROACH TO SOME PROBLEMS OF DIFFERENTIAL DIAGNOSIS AND EDUCATION WITH SPECIAL REFERENCE TO HEARING.

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DESCRIPTORS- *TRAINABLE MENTALLY HANDICAPPED, *AUDITORY TRAINING, AUDITORY PERCEPTION, *HANDICAPPED CHILDREN, *AURALLY HANDICAPPED, *PERCEPTION TESTS, SENSORY EXPERIENCES, AUDITION (PHYSIOLOGY), HOUSTON, TEXAS

THE PROBLEM OF THIS RESEARCH WAS TO DEVISE A NEW, NONVERBAL AND NONLANGUAGE PROCEDURE FOR TESTING THE HEARING OF MENTALLY RETARDED CHILDREN IN WHICH IMPAIRMENT IN DISCRIMINATING PURE TONES AT THRESHOLD LEVELS WOULD NOT BE CONFUSED WITH IMPAIRMENT OF AUDITORY SENSITIVITY. OPERANT CONDITIONING TECHNIQUES WERE APPLIED TO TRAINABLE MENTALLY RETARDED, NORMAL, AND PHYSICALLY HANDICAPPED CHILDREN IN THE MEASUREMENT OF PURE TONE HEARING THRESHOLDS. RESULTS WERE COMPARED WITH THE THRESHOLDS OBTAINED PREVIOUSLY BY AUDIOMETRISTS EXPERIENCED IN EXAMINING EXCEPTIONAL CHILDREN WITH CONVENTIONAL METHODS. A PANEL EQUIPPED WITH LEVERS WAS USED WHICH, WHEN OPERATED UPON SOUND, DISPENSED REINFORCERS. WHEN THE SUBJECT PUSHED A SPECIFIC LEVER, REINFORCERS APPEARED AND SOUND DISCONTINUED. SOUND CAME FROM EARPHONES OR LOUDSPEAKERS AND WAS CONTROLLED BY AN OBSERVING OPERATOR. THE OPERANT CONDITIONING PROCEDURE PROVIDED VALID AND RELIABLE MEASUREMENTS OF HEARING THRESHOLDS IN THE MENTALLY RETARDED CHILDREN. THE RESULTS OBTAINED, AFTER EXPERIMENTATION WITH 67 CHILDREN SUPPORTED THE BELIEF THAT THE PROCEDURE WAS AN EFFECTIVE ONE. RECOMMENDATIONS FOR MORE STUDY WERE SUGGESTED. (GC)

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The Measurement of Sensory Thresholds in Exceptional Children:

an experimental approach to some problems of differential diagnosis and education with special reference to hearing

Cooperative Research Project No. 418

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University of Houston

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FOREWORD

This report represents an initial step of an attempt to adapt to the study of human behavior some principles of operant conditioning that have proved their value in the study of animal behavior. Like other studies which build on a firm theoretical basis and a body of experimental knowledge, this research has illuminated many more problems for further fruitful investigation than were perceived at the outset. We have been sorely tempted at times to pursue some of the tantalizing observations, tangent to the main research problem, that have been made in the course of experimentation. Except for a few studies that have been followed up by our students, we have resisted this lure in the hope that later investigation will be possible; and in this report we have simply mentioned some of the intriguing possibilities.

It is clearly evident to us that the operant conditioning laboratory offers a new and valuable tool in the study of some basic problems of child psychology, and it may have unique values for the diagnosis and treatment of exceptional children which go considerably beyond existing techniques for classification and therapy.

The present report, however, deals primarily with the refinement of a method for the solution of a single diagnostic problem of a single disability group: namely, the development of a new method for measuring the auditory acuity of mentally retarded children.

In order to meet the separate needs of two groups of anticipated readers, several overlapping inserts of technical detail and discussion have been set off from the main body of the report. The general narrative is a relatively non-technical overview of the nature of the problem, the work done and the results obtained that we hope will be intelligible to the educator of the mentally retarded, the speech and hearing specialist, and the informed layman. The indented, single-spaced material offers a more precise and detailed description which may be of interest to the active researcher in operant conditioning.

Although this is a "final" report in the sense that the contract with the Office of Education has been fulfilled, it will be evident that we have simply crossed the frontier of a rich territory the topography of which is only barely perceived and whose potentialities remain to be explored. It is gratifying in this connection to report that the potentialities of the research have been recognized by Foringer & Co., a leading supplier of instruments for behavioral research. Foringer & Co. will display an operating prototype of our apparatus at the annual convention of the American Speech and Hearing Society (Los Angeles, November 1-5, 1960) and it is expected that a commercial model will be available for sale to investigators and institutions by January 1, 1961.

We are indebted to Mr. John Mabry, our research associate; Mr. Frank Borreca, Mrs. Weldon Henderson and Mr. Richard Dobyns for invaluable help in obtaining subjects; and to Mrs. Elizabeth McAuliffe, general factotum and typer of the manuscript.

Most of all, of course, we are indebted to the numerous individuals whose willing service as our subjects made this report possible.

Lee Meyerson
John L. Michael

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THE PROBLEM

Almost all studies of the auditory acuity of the mentally retarded have shown that this group responds less readily to auditory stimuli and appears to have a considerably higher incidence of hearing loss than is found in normal populations (Birch and Matthews, 1951; Foale and Paterson, 1954).

This finding, however, usually has been interpreted uncritically as meaning that there are proportionately more, and more severe, cases of physiologically impaired hearing among the mentally retarded than in other groups; but this is not self-evident. We do not make similar assumptions with respect to physiological capacity when the high incidence of impaired visual perception and the high prevalence of speech defects among the mentally retarded are shown. It is not clear either that such an assumption is justified with respect to auditory acuity.

First, practically all investigations have measured the mentally retarded child's voluntary response to pure tones. This is a difficult task for the young normal child (Meyerson, 1956). For the mentally retarded child, his difficulties with language and with responding appropriately to verbal instructions, his limited attention span and shallow motivation during the testing procedure, and his lack of responsiveness to such necessarily "abstract" stimuli as pure tones might lead one to predict the high incidence of apparent hearing impairment that has actually been reported. The briefness of the testing period, infrequency of retesting and the limited attention paid to repeated teaching

of the task to the mentally retarded child also point in the same direction.

Second, educators of the mentally retarded, by experience or intuition, appear to be aware of this interpretive problem for they have isolated a central, perceptual learning task, amenable to training, that has been neglected by investigators who have emphasized only an apparent, peripheral sensory deficit. Moss, for example, points out that of four major aims of local school system programs for the mentally retarded, one was "To improve perception (visual and auditory)."

Our major problem, therefore, was to devise a non-verbal, non-language, and relatively non-intellectual procedure for measuring auditory acuity in mentally retarded children which avoids the difficulties encountered with existing procedures. In particular, the procedure must not confound failure in discrimination with failure in sensation.

The value of a good measure of sensory deficit, suitable for use with the mentally retarded, in differential diagnosis, plan of educational treatment, and educational prognosis has long been recognized. As Matthews (1957) remarked with respect to the difficulty of differentiating hearing loss and mental retardation and the great difficulty of confirming their joint existence in the same child, "Most of the differential diagnosis techniques referred to are based on rich clinical experience. There is little validation information about any of them." It seems clear that procedures devised and validated for the mentally retarded and capable of isolating peripheral sensory defects from central impairments would be of great value.

RELATED RESEARCH

Hearing

Foale and Paterson in Scotland (1954) and Birch and Matthews in the United States (1951) reported that 33 per cent and 50 per cent, respectively, of the mentally retarded groups they studied responded to a pure tone test as if they had some loss of hearing. Their studies are representative of recent work in this field. Although there is a varying incidence of hearing loss reported by different investigators, all are in agreement that it is much greater among the mentally retarded than in non-retarded groups.

Meyerson (1956) investigated the sources of difficulty in the pure tone testing of young children and validated a test of hearing for speech. He showed that acuity for pure tones and acuity for speech stimuli were not identical and that educable mentally retarded children who had normal hearing for pure tones had diminished acuity for speech. He concluded that hearing for speech is a learned function.

Operant Conditioning Methodology

Blough (1955) described a promising operant conditioning method for measuring visual thresholds in the pigeon which in turn was adapted from the Bekesy technique (1947) for measuring human auditory thresholds.

The Bekesy technique requires the subject to hold a switch closed while he can hear a tone and to release the switch when he can no longer hear it. An automatic mechanism built into the Bekesy audiometer attenuates the tone at the rate of a few decibels per second when the switch is closed, and increases the

intensity of the tone at the same rate when the switch is released; and the audiometer also automatically changes the tone from one frequency to another. By pressing the switch when he hears the stimulus and releasing the switch when he does not, the subject causes the sound level produced by the audiometer to cross his absolute threshold several times before the next frequency is presented. Inasmuch as the intensity and frequency of the sounds and the responses of the subject are traced on moving chart paper, the threshold value of any frequency can be easily obtained by computing the average of the reversal points on the graphic record.

Using operant conditioning procedures developed by B. F. Skinner (1938) and ingenious visual apparatus, Blough (1955, 1958) adapted the Bekesy method of measurement to the determination of visual thresholds in the pigeon, as follows: A pigeon under food deprivation was taught to peck a circular response key, mounted in the wall of the experimental chamber in which it was confined, by making food reinforcement contingent on this response. In the beginning, a single peck on the key caused a food tray to be made available to the bird for a few seconds. Later, when a stimulus light was visible to the pigeon through an aperture above the key, pecking the circular key was not reinforced: i.e. the food tray did not appear. However, pecking a triangular key mounted immediately below the circular key turned the stimulus light off, and when the stimulus light was off, pecking the circular key was again reinforced by the appearance of the food tray. When the food tray was removed, the stimulus light came on again. The food was an unconditioned reinforcer for pecking the circular key;

and the stimulus condition, light off, was a conditioned reinforcer for pecking the triangular key.

To produce stable, high-rate responding for long periods, variable ratio reinforcement was gradually introduced on both keys. If the light was visible, a variable number of pecks on the triangular key would turn it off. When the light was off, a variable number of pecks on the circular key would deliver food. If each response on the triangular disk was then made to reduce the illumination by a small amount rather than turn it off completely, and if each response on the circular disk was made to increase the illumination by a small amount, the pigeon plotted its own absolute threshold in a manner similar to the human subject using the Bekesy audiometer.

To ensure that the responding was under the control of the light stimulus, the following conditions were imposed:

1. Instead of the light onset occurring after every food delivery, it was programmed to stay off after one-fifth of the food deliveries. Further pecking on the circular key when the light was off was reinforced with food.

2. Errors were penalized. Each peck on the circular key when the light was on and each peck on the triangular key when the light was off subtracted one response from the accumulated sum of correct responses so that reinforcement was delayed.

3. To increase the likelihood of looking at the stimulus aperture, a pause between switching from the triangular to the circular disk was made mandatory. If the bird turned off the light and pecked the circular key within less than .2 second after his last peck on the triangular key, the light came on again and the bird had to start over on the triangular key.

4. To increase the time the stimulus remained on and thereby to permit more threshold crossings per session, a variable interval timer was started when the stimulus light came on. This timer had a variable duration with an average of 45 seconds. Until it timed-out no amount of responding on the triangular key turned off the light, although each peck attenuated it slightly; and no amount of responding on the circular key provided food, although each peck increased the stimulus intensity slightly. When the timer completed its operation, the variable ratios and other contingencies described above went into effect.

> A typical performance might go as follows: Food has just been delivered and the stimulus light has come on. The bird pecks the triangular key, gradually decreasing the stimulus intensity, until it is below its threshold. It then pecks the circular key which increases the stimulus intensity. When the stimulus affects him, he switches to the triangular key and again drives the stimulus intensity down, etc. Eventually the variable interval timer completes its cycle. Assume this occurs when the stimulus intensity is reasonably high. Pecks on the triangular key decrease the intensity and the fourth peck turns it off completely. The bird then switches to the circular key and after a variable number of responses (average: 8) receives food.

In brief, under specified controlled conditions, the pigeon learns to peck the triangular key to turn off the stimulus light and then to peck the circular key to receive food. The apparatus is then altered so that pecks on the triangular key gradually reduce the intensity of the stimulus light and pecks on the circular key gradually increase it. The ultimate result is that the pigeon oscillates between pecking the triangular key when the stimulus is visible and pecking the circular key when it is not. Inasmuch as each peck on the triangular key gradually decreases and each peck on the circular key increases the intensity of the stimulus, the bird drives the visual stimulus first below, then above, his threshold in much the same way as a human in the Bekesy procedure. A continuous record of the intensity of the stimulus and the responses made allows an unambiguous threshold value to be computed. The technical insert above describes the conditions which make this result possible.

This procedure has been used successfully in the study of the dark adaptation curve in pigeons (Blough, 1956), the effects of drugs on the absolute visual threshold of pigeons (Blough, 1957)

and the effects of ototoxic drugs on the auditory thresholds of rats (Gourevitch, et al., 1960).

Operant Conditioning of Children

That a procedure is effective with pigeons or rats, of course, is no assurance that it will be equally effective with children. Children, in our culture, cannot be subjected to long periods of food deprivation nor can they be involuntarily confined in experimental cubicles. There are also social limitations upon the kind and extent of positive reinforcers that an experimenter may use. Nevertheless, there are many reinforcers, less powerful than food to a hungry organism, which appear to be entirely adequate to condition and maintain a desired behavior.

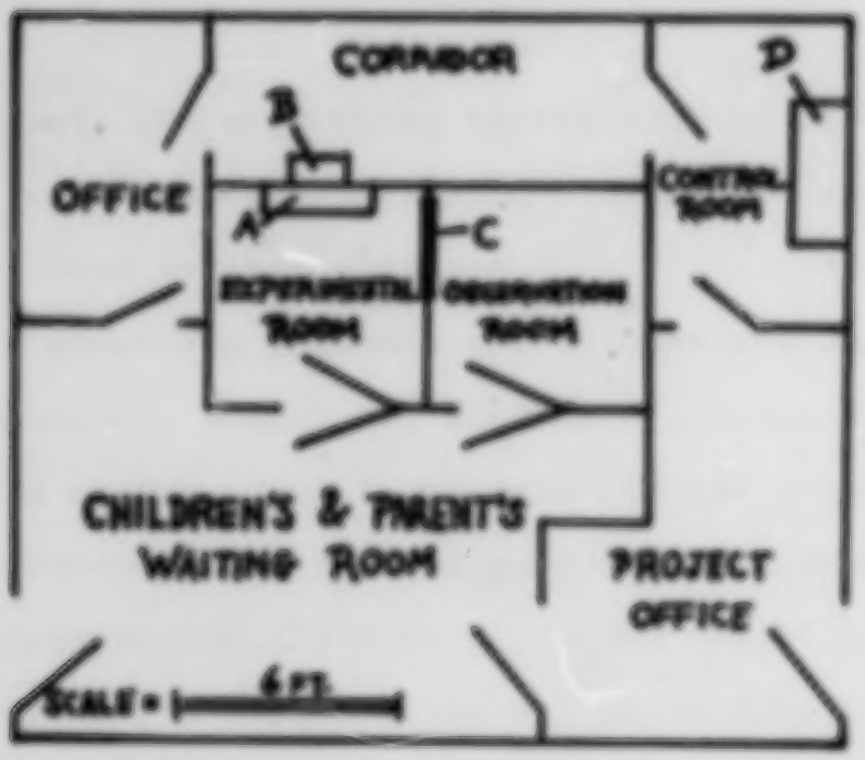
That children will perform for reasonable periods in experimental operant conditioning situations has been demonstrated by Bijou (1958), Long, et al. (1958), Ellis, et al. (1960) and others. The first two investigators reported that small trinkets of the kind dispensed by vending machines reinforce the plunger pulling behavior of children, on the Lindsley manipulandum, in much the same manner as food reinforces and maintains a desired behavior in lower animals. The third investigator working with mentally retarded teen-agers and adults in an institutional setting found that candy and cigarettes were effective reinforcers.

EXPERIMENTAL WORKSPACE, APPARATUS AND REINFORCERS

The floor plan of the children's operant conditioning laboratory is shown in Figure 1a.

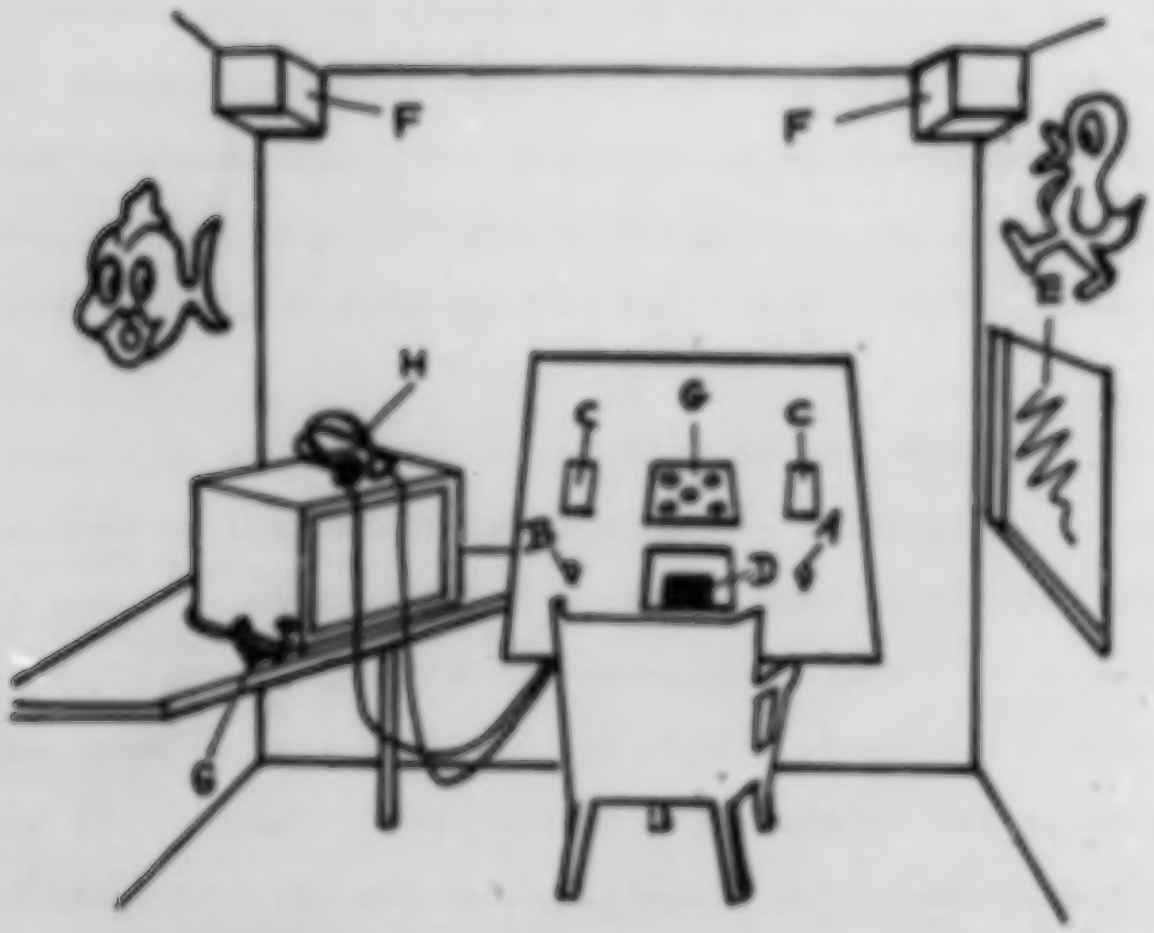
The experimental room, 6' x 6' x 9', contained a chair placed in front of a panel; a small shelf to the left of the panel on which a box was fastened; and an intercom and a loud speaker attached to opposite corners of the ceiling above the panel. A 3' x 2' one-way vision mirror was part of the wall separating the experimental room from the observation room. All of the walls, except the mirror, were constructed of two panels of insulating hardboard placed five inches apart, packed with sound insulating fluff, and covered on external surfaces with acoustic tile. Double doors, covered with acoustic tile, separated by two inches of airspace, and edge-sealed with rubber were used to seal off the experimental and observation rooms from the rest of the laboratory. Ambient noise level as measured by Circuit A of the General Radio Sound Level Meter No. 1262A in these rooms was of the order of 30 decibels (re 0.0002 dynes/cm^2). Vigorous operation of the levers, described below, raised the sound pressure level to about 60 db measured on the same circuit.

Figure 1b is a schematic diagram of the contents of the experimental room. The shelf and box to the left of the panel were not used in this research. The panel itself was equipped with two plunger-type Lindsley manipulanda or levers, each with a white stimulus light above it; a feeder tray containing a light which was automatically turned on when a reinforcer was delivered; and plug-in connections for the earphones which were



A – Panel B – Feeder C – Mirror D – Control Equipment

FIGURE 1a. Floor Plan of the Laboratory



A – Right-hand Lever B – Left-hand Lever C – Lever Lights
D – Reinforcer Delivery Tray E – One-way Mirror F – Speakers
G – Equipment present but not used in this study H – Earphones

FIGURE 1b. Schematic Diagram of Experimental Room

mounted underneath the protruding bottom edge of the panel. The five-light stimulus panel located between and above the two levers was not used in this research.

Figure 2a shows the contents of the observation room--a recording attenuator, commercial audiometer, intercom master controls, and a switch console connected to the programming and recording equipment in the control room. The programming and recording equipment, not illustrated, consisted of a power supply, timers, relays, stepping switches, pulse formers and recorders such as are common laboratory equipment for behavioral research. Recorders are available from Davis Scientific Instruments (Studio City, California) and Ralph Gerbrands Co. (Cambridge, Massachusetts). Gerbrands is also the maker of the Lindsley manipulandum. The programming equipment was a mixture of modular units manufactured by Foringer & Co. (Rockville, Maryland) and the Grason-Stadler Co. (West Concord, Massachusetts).

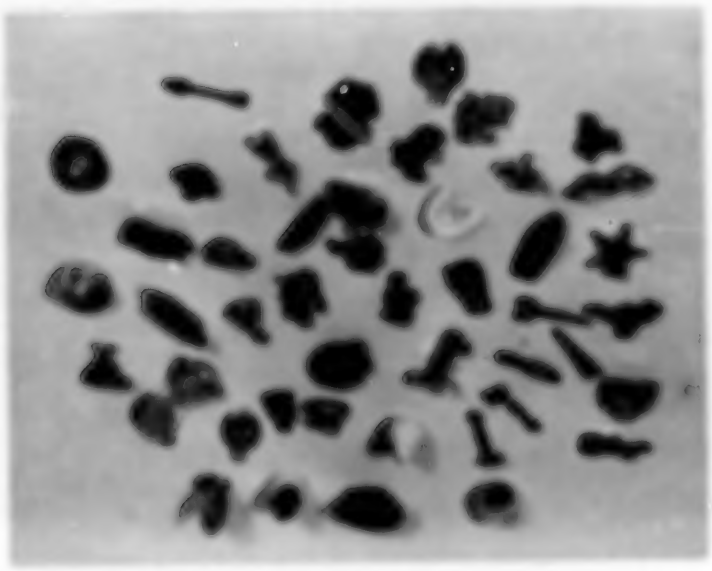
Figure 2b shows part of the view of the subject that could be obtained by the experimenter from the observation room.

A small selection of the trinkets used as reinforcers is shown in Figure 3. Figure 3a shows miniature toys and play objects, some scraps from the laboratory shop, and a used hearing aid battery. The reinforcing value of nails, screws, hinges and batteries was not originally anticipated, but children appear to be relatively undiscriminating collectors. Figure 3b shows a variety of inexpensive rings and charms. Figure 3c shows miniature personal and household objects that are fascinating to most children. In addition to the kinds of

FIGURE 2a. Equipment of Observation Room

FIGURE 2b. View of Subject from Observation Room

a. Miniature Personal and Household Objects



b. Rings, Charms, Miniatures

c. Miniature Toys, Play Objects and Scraps

FIGURE 3. Reinforcers

objects illustrated, extensive use was made of a wide variety of edibles--mainly candies, crackers and nuts. At least 300 different objects were usually available at one time, but it would be possible with little effort to obtain many times that number. The major sources of supply for trinkets were the Paul A. Price Co. (55 Leonard Street, New York, N.Y.) and Samuel Eppy & Co. (91-15 144th Place, Jamaica, N.Y.). Both companies can supply varied "mixes" for $8-16 per thousand.

SUBJECTS AND GENERAL PROCEDURE

Subjects

The subjects of this research may be classified as follows: Twenty mentally and physically normal children, 2 to 6 years of age, were used in the initial stages of the investigation. Twelve mentally retarded children, 5 to 14 years of age, were used in the first portion of the investigation devoted to methodological refinement of procedures. Thirty-five, 5 to 19 year old, mentally retarded children, of which seventeen had threshold measurements made, were used in the final procedure. In addition, four, 9 to 12 year old, physically normal children, five, 8 to 14 year old, deaf children, and four normal adults were used in the final stage of the investigation. More detailed classification of the subjects, except for those used in the initial, exploratory stage of the research, is shown in Tables 1, 2, 3, and 4.

General Procedure

Operant Conditioning. A child was brought to the waiting room and was told or shown that he could get some toys, candy and trinkets in the experimental room, and he was given a transparent plastic bag in which to hold them.

In the beginning, a parent who was present was allowed to sit in the experimental room if the child wished it. It was soon discovered that this was a mistake, for the parent's presence had a distracting and interfering effect upon the children. Beginning with the second group of mentally retarded children, therefore, the subjects were transported to and from school by a research assistant, and parents were not involved.

Once the child was in the experimental room, three degrees of force were used to initiate the pulling of the lever. First, the experimenter motioned toward the right hand lever and said, or pantomimed, that pulling it would produce a reward in the feeder tray. Second, if the lever was not pulled, the experimenter demonstrated the operation and presented the child with the reward. Third, if the child remained passive, the experimenter placed the child's hand on the lever and pulled with him so as to deliver another reinforcer. The experimenter then left the room, and if the child did not object, closed the door behind him.

If, after these instructions, a child did not start pulling the lever, the experimenter, from the observation room, began a process of "shaping-up" lever pressing behavior by differential reinforcement of successive approximations: that is, a reinforcer was delivered for any approximation to lever pressing, such as looking at the lever. As looking became more frequent, reinforcement was withheld until the lever was touched and finally pulled.

A decreasing number of children required "shaping-up" as the experimenter learned to refrain from urging the child to comply. Friendly behavior without concern about whether the child pulled the lever or not and a relaxed waiting for the child to proceed at his own pace was found, by experience, to be the most effective way of reducing and shortening emotional behavior.

Several training methods for different groups were employed. Under conditions described in the next section, the basic sequence initially was as follows: 1) Responding on the

right lever was established. 2) Responding on the right lever only in the presence of a sound stimulus from the loudspeaker was established. 3) Responding on the right lever only in the presence of a sound stimulus from the loudspeaker and responding on the left lever in the absence of a loudspeaker, sound stimulus were established. If the discriminative responding developed adequately, the experimenter reentered the room and placed earphones on the subject.

Later, it was found that better results were obtained if the initial discrimination to sound was aided by correlating a light over the right lever with the tone-on condition and a light over the left lever with the tone-off condition. The light was then gradually faded, leaving the responding under the control of the tone from the loudspeaker until the earphones were introduced.

Most experimental sessions were arranged to last approximately 30 minutes. If a child left the room voluntarily before that time, he was returned to his parents or the institution from which he had come. If the child wished to continue beyond 30 minutes, the experimenter usually entered and indicated that the session was over.[1]

Hearing Testing. In preparation for comparing the hearing thresholds of mentally retarded children obtained by operant conditioning and by standard audiometric procedures, seven children were referred for examination to a speech and hearing

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1. In a few instances a child was allowed to continue. One 2-year-old worked the apparatus for 55 minutes and left unwillingly. Another pre-school child worked for two hours without apparent satiation.

center. As anticipated, five of the seven children were reported to have serious hearing losses or to be unresponsive to pure tone stimuli. Unfortunately, however, the otologic examination, required by the hearing center, was so traumatic to the children it was impossible to induce the children or their parents to cooperate further in the operant conditioning portion of the experiment. Subsequently, therefore, the subjects were simply screened by one of the experimenters using the common criteria for hearing loss of 20 db loss at one frequency or 15 db loss at two or more frequencies. Approximately half of the children showed hearing losses of this magnitude or were not amenable to pure-tone testing.

METHODOLOGICAL DEVELOPMENTS AND RESULTS

Pilot Work with Normal Children

In order to become familiar with the kinds of problems that arise in experimental operant conditioning work with children, twenty normal, nursery school children, enrolled in the University of Houston laboratory school, were studied over a period of three months.

Reinforcers. Two initial problems were to discover the characteristics of effective reinforcers for children and to obtain a plentiful supply of them. Aside from the hope that inexpensive reinforcers could be obtained and the belief that a large variety was desirable, the only limitation on what could be offered the children was the size of the object. The automatic feeder which dispensed reinforcers would not accept objects larger than 3 x 1 x 1 inches.

It was found that small candies, salty crackers and nuts, commercial trinkets, and laboratory junk were effective and inexpensive reinforcers. The edibles are available in any grocery store, the junk in any laboratory, and the trinkets from commercial supply houses (cf. p.13).

The variety of available reinforcers appeared to be an important variable. Long et al. (1958), who used a limited variety of reinforcers, reported considerable difficulty in keeping his child subjects in the experimental room, but that was not the case in the present work. In general, as long as the reinforcers kept changing, the children were willing to work at the apparatus.

At first objects which might involve considerable time to consume or which might seduce the children into play or induce satiation were deliberately avoided. For example, miniature Hershey bars were not used because they had to be unwrapped and consumption of a few could be quite filling. It was found that these fears were groundless. Children, in general, did not eat very much of the candy at the time it was received, particularly wrapped candy, but simply placed it in their plastic sacks.

Similarly, initial concern about general satiation effects was found to be unwarranted. A program which allowed the children to receive as few reinforcers as possible was soon abandoned in favor of a much more liberal program. It was found empirically that in a half-hour session of rapid performance in which a child may receive as many as 100 or 200 objects, satiation does not occur if a sufficiently wide variety of objects are available as reinforcers, and the child is assured that he may keep all the trinkets he receives.

Manipulanda. Another series of problems related to the Lindsley manipulanda. First, a few children, as anticipated, pulled both levers simultaneously or alternated rapidly using one hand on each lever. This was not a serious problem since such patterns were never followed by reinforcement. However, it would be desirable in future work to render these behaviors mechanically impossible since they did add to the duration of unreinforced responding.

Second, a more serious problem arose because of the resemblance of the manipulanda to the knobs found on commercial

candy machines. The children's hard, forceful pulls on the levers, which undoubtedly are effective responses to commercial machines, were needlessly tiring and irritating to their hands. Ultimately, gentle easy pulling develops, but it would be more efficient to avoid the problem by a different lever design. Effortful pulling is not compatible with careful listening behavior.

Third, the manipulanda produced considerably more noise, about 30 db above the ambient level, than is desirable in a procedure for testing hearing. For further work, it would be preferable to design a quiet manipulandum on the order of a telegraph key, a slider, or an hydraulically operated lever.

Earphones. Moving coil earphones, of the kind commonly used with audiometers, are heavy. They become annoying, if not actually fatiguing to a young child toward the end of a 30-minute session. Suspending the earphones from the wall or ceiling, so that little of the weight rests on the child, is desirable.

Discriminative Stimulus. Unlike the procedure employed with animals in which absence of light or sound was the discriminative stimulus, the present research began by using the presence of sound as the discriminative stimulus. This change in procedure was imposed because it was desired to develop a method both for independent hearing testing and for preliminary hearing training as a preparation for later threshold measurement by standard audiometric techniques. For the latter purpose, it was believed that developing tones as a stimulus in

the presence of which reinforcement was not available would lead to tones acquiring aversive properties; and that, of course, would be undesirable.

Automatic Programming. In experimenting with the various components of the automatic Blough-Bekesy procedure, particularly variable ratio schedules with a preceding variable interval, and observing the resulting behavior of the subjects, it was evident that automatically programmed schedules resulted, on the one hand, in many missed opportunities for an effective reinforcement and, on the other hand, accidentally reinforced undesirable responses. For example, children often responded to the panel as they do to commercial vending machines by pounding on it when a reinforcer did not follow a lever pull. On an automatically controlled schedule, a sequence of pounding sometimes would be followed by a reinforced lever pull, and this would maintain the pounding behavior for some time. Similarly, other kinds of "superstitious" behavior would be reinforced rather than extinguished. However, as later work showed, this kind of problem was not as serious as was believed at the early stages of the research.

In general, the problems of the automatic program modeled on the Blough-Bekesy procedure revolved about attempts to overcome two important differences between the procedures that are possible in a typical, free-operant experiment with animal subjects and the procedures that are possible when children are the subjects. First, children ordinarily cannot be locked in the test chamber. Second, trinket and tidbit reinforcement for well nourished and reasonably well gratified children hardly has the

effectiveness of food reinforcement for a severely deprived animal. These two conditions rendered ineffective any use of prolonged extinction or punishment contingencies to improve discriminative behavior, inasmuch as the children simply left the room when the general probability of reinforcement in the test chamber failed to compete favorably with the probability of reinforcement outside or back at school. Some children, nevertheless, did learn to discriminate between tone and silence, but it was clear that the procedure was by no means optimal.

For these reasons, the automatic apparatus which programmed the stimulus presentations, the response control of the stimulus intensity, and the reinforcers was eliminated in favor of an experimenter-controlled procedure.

Experimenter-controlled Procedure. In this procedure the experimenter while observing the subject through a one-way vision screen took maximum advantage of momentary changes in the child's behavior to shape up the desired responses of pulling on the right lever while the tone was on and pulling the left lever when the tone was off. The experimenter had direct control over the stimulus frequency and intensity and the contingencies of reinforcement.

Using the experimenter-controlled procedure, it was possible to obtain a measure of free-field hearing thresholds of several children by observing how they switched from one lever to the other as they perceived or did not perceive the stimulus presented by the experimenter. At this point the basic procedure was considered to be sufficiently stable to justify initial work with mentally retarded subjects.

Pilot Work with Mentally Retarded Children

This phase of the research had two major goals: the first was simply to become familiar with the behavior of mentally retarded and brain damaged children in the experimental situation; and the second was to perfect the observer-controlled procedure.

Work was begun with severely damaged or retarded children who were believed by the school and by the experimenters to be untestable by standard audiometric methods. This was poor strategy, for several of these children did not "like" either food tidbits or trinkets, and most of them could not be reinforced by the objects that were available. Attempts to discover additional reinforcers, primarily of a visual or vibratory nature, produced a number of interesting observations and leads for further research, but as they were tangential to the main research objective, they were not followed up at that time.

Table 1 shows some characteristics of these children by sex, C.A., I.Q., diagnosis, and qualitative performance in the operant conditioning situation. The I.Q. and diagnostic categorization were taken from the records of the school from which the children came and no attempt was made by the present investigators to verify them independently.

It will be seen that of the twelve brain damaged or severely retarded children studied, only seven were responsive to the available reinforcers to a degree that would permit auditory measurement. Three of the remaining five appeared to be unreinforceable, and performance of two subjects was obscured by the distracting influence introduced by the presence of a parent.

Of the seven children who were reinforceable in some degree, it was possible to measure hearing thresholds easily, using the

TABLE 1

Qualitative Operant Conditioning Findings for First Group of Brain Damaged or Severely Retarded Children Using Observer-Controlled Stimuli and Reinforcement

Subject	Sex	Initial CA	S-B IQ	Diagnosis	No. of Sessions	Experimenter's Comments
JB	m	6	30	mongoloid	2	Excessive emotional behavior toward mother.
DB	m	7	*	undifferentiated	3	Unreinforceable with reinforcers available.
WB	m	11	29	mongoloid	2	Good performance for all frequencies under free field conditions.
MB	m	6	54	brain damaged	1	Good performance for some frequencies under free field conditions.
PC	f	14	34	brain damaged	7	More interested in returning to home or school than in reinforcers.
GG	m	9	*	psychotic	4	Good performance for all frequencies under free field conditions, but would not wear earphones.
RL	m	5	60	brain damaged	6	Responded accurately at 30 db for most frequencies under earphone conditions.
CL	f	6	*	mongoloid	4	Excessive emotional behavior toward mother. More interested in returning to home or school than in reinforcers.
KM	f	6	25	brain damaged	5	Groggy from anti-convulsant drug; went to sleep. Unsuccessful.
JC	m	7	*	blind (retrolental fibroplasia) and retarded	3	Initially, emotional and unreinforceable. Later, responded well to music and candy.
GH	m	7	*	brain damaged	1	Unreinforceable; left reinforcers in tray without examining.
BR	f	6	*	physical deformity and retarded	3	Responded accurately at 30 db for all frequencies under earphone conditions.

* untestable

observer-controlled procedure, in two instances. In the other five cases, it was clear that further extensive training or a different schedule would be required inasmuch as the discrimination procedure appeared to be too difficult or too aversive to the children and little useful learning took place in the experimental room. It also became quite clear that the observer was not capable of accurately controlling the stimulus and reinforcing conditions as these conditions became more numerous and more complex.

This portion of the research led to the following conclusions:

Some mentally retarded and brain damaged children appear to be unreinforceable by the usual reinforcers and a search must be made for unusual ones.

An observer-controlled, operant conditioning procedure is an adequate and effective means of obtaining threshold measurements of hearing in some mentally normal and some mentally retarded children. In addition, it probably would be an optimal preliminary training procedure for young or "difficult to test" children prior to attempting threshold measurement by standard audiometric techniques. For many subjects, however, especially mentally retarded subjects, an observer-controlled procedure becomes too complex for the experimenter to cope with, and eventually it breaks down. For these subjects only a completely automatically controlled procedure is likely to be successful.

At this point a renewed attempt was made to develop an automatic schedule for the operant conditioning measurement of auditory thresholds.

Automatic Procedures with Mentally Retarded Children: General Description

During the central and major portion of the research, three increasingly satisfatory procedures were developed that automatically dispensed reinforcements according to a pre-arranged electronic programming schedule. Experimenter action or judgment was required only in switching from one frequency to another, attenuating the intensity of the stimulus, and judging when the stimulus was at threshold intensity for a subject by observing the accuracy and promptness with which he switched from one lever to the other in response to the presence or absence of the stimulus.

Subjects in this phase of the work were thirty-five mentally retarded children, 5 to 19 years old and of various diagnostic categories, who were studied over a period of 8 months. The children were transported to and from the University laboratory in groups of two or three by a research assistant; a parent, teacher or other person known to the child was never present. No difficulty was encountered in having one or more of the children wait while another child was working the apparatus, and behavior in the laboratory was generally appropriate and satisfactory even though few of the children had any understanding of the nature of the experiment or its relationship to hearing. To the children, the experiment was simply an opportunity to obtain some toys by pulling two different levers at different times--a discrimination that most could make although their verbalizations about the procedure were usually vague and often wrong.

Initial Procedure. This procedure was essentially the same as the one used earlier in the pilot work with normal children. It was employed long enough to ascertain that mentally retarded children responded to it in much the same way as mentally normal children and there were no simple ways of overcoming its disadvantages.

The Lever-Light Procedure. In this procedure the 1.5 x 2 inch translucent panel above the right lever on the response board (cf. Figure 1b) was lit when the child entered the experimental room, and the panel above the left lever was dark. Simultaneously, a 500 cycle tone at 40 to 50 db was being delivered from the loudspeaker mounted at the ceiling. The child was seated in front of the response board and earphones placed over his ears. If the child accepted the earphones, the sound was immediately channeled from the loudspeaker to the phones. If the child rejected the earphones, they were removed temporarily and the loudspeaker remained the sound source. In either case, almost all children immediately pulled the lever on the right below the lighted panel. When this was done, a trinket was dispensed, a light went on momentarily in the trinket receiving tray, the overhead laboratory light dimmed momentarily, the panel above the left lever became illuminated while the panel above the right lever went dark, and the sound stimulus ceased. The stimulus change was so striking that, after examining the trinket reinforcement and placing it in his plastic bag, a subject readily began to pull the lever on the left, for it was the left panel that was now illuminated. Pulling the left lever

resulted, via the electronic programming schedule, in switching the illumination to the panel over the right lever and to the simultaneous onset of the sound stimulus, but it was not reinforced with a trinket. At this point, the cycle would be repeated. Pulling the right lever would yield a trinket reinforcement, cessation of the sound stimulus and switching of the illumination to the left panel.

It was expected that after the panel lights were gradually faded and the discrimination came under the control of the sound stimulus alone that the subjects would respond only to the right lever in the presence of a tone and only to the left lever in the absence of a tone. However, attempts to achieve stable responding with this procedure were not entirely successful. Difficulties arose from two main sources. First, responding to the left lever was never directly reinforced but was simply a means of initiating the tone-onset condition under which reinforcement could be obtained if the right lever was pulled. This constitutes extinction or unreinforced responding for the left lever, and stable performance under these conditions is difficult to obtain. It is not surprising, therefore, that response to the left and right levers was asymmetrical. Second, the cessation of the sound stimulus always coincided with the delivery of the trinket reinforcement, and this was not an optimal condition for developing the tone-on::tone-off discrimination. Accordingly, a final procedure was developed that was markedly different from the Blough technique from which the research originally started.

Final Procedure. The set-up for the final procedure was similar to the lever-light procedure. It was more effective than the lever-light procedure because it allowed reinforcement on both the right lever and the left lever and the stimulus change never occurred at the same time as trinket reinforcement. The procedure was as follows:

The translucent panel above the right lever on the response board is lit when the child enters the experimental room and the panel above the left lever is dark. Earphones delivering a 500 cycle tone at 40 db are placed over his ears if he will accept them; otherwise the tone is channeled to the loudspeaker mounted on the ceiling. As before, the apparatus is wired so that on every trinket delivery a light goes on momentarily in the trinket receiving tray and the overhead laboratory lights dim momentarily. When the child pulls the lever on the right under the illuminated panel, a trinket is dispensed, the panel above the left lever becomes illuminated while the panel above the right lever goes dark, and the sound ceases. Pulling the lever under the now illuminated left panel and in the absence of the sound stimulus results in trinket reinforcement, the switching of the illumination to the right panel, and the onset of the sound stimulus. Thereafter, each panel light remains on for a variable period of time until the child learns that pulling the lever below the illuminated panel "pays off" while pulling the lever below the dark panel does not. During this period and subsequently, the sound stimulus is "on" only when the right panel is illuminated. The program is scheduled

so that the subject receives from one to three separate reinforcements, on a low variable ratio schedule, for pulling the lever below the illuminated panel, and then his own further responding, instead of yielding another reinforcement at this critical choice point, automatically causes the electronic programmer to switch the illumination to the panel above the other lever. Inasmuch as there is a sound stimulus from the earphones or loudspeaker when the right panel is illuminated and no sound stimulus when the left panel is illuminated, it is apparent that the discrimination is or can be under the control of two kinds of stimuli. Stable performance for this discrimination usually can be achieved in one 30-minute session, although some children may require as many as three or four sessions. From 80 to 150 trinket reinforcements may be given in each session.

In the following session, the observer gradually decreases the illumination of the panel lights to zero so that the lever pulling is brought completely under the control of the tone: when the tone is "on" the right lever "pays off" and when the tone is "off", the left lever "pays off" in trinket and candy reinforcements. Tones of different frequency are presented in sequence. In each case, it should be mentioned again, it is the child's own responding that switches the tone on or off; more than one reinforcement may be available on the same lever before the stimulus conditions change; and no reinforcement is given at the time the stimulus changes from "off" to "on" or from "on" to "off". Stable performance for this discrimination

usually can be accomplished in one 30-minute session. As in the previous discrimination, either observation of the subject from the control room or the automatic recording and counting of errors by the electronic programmer permits easy interpretation of the adequacy of the discrimination.

In the final session the frequency of the sound stimulus is systematically rotated several times among tones of 500, 1000, 2000, and 4000 cycles per second at 40 db for the two lower frequencies and 50 db for the two higher frequencies so that the subject responds easily to any one of the frequencies. This generalization training appears to be necessary as children who respond well to a tone of 500 cps do not necessarily respond immediately to tones of higher frequency. In our experience, discrimination broke down considerably in the presence of the higher frequencies. When discrimination is well established for all frequencies at levels well above threshold, however, it is a simple matter to decrease the sound stimulus in 5 or 10 db steps while sweeping from frequency to frequency. If generalization training has been adequate, and accurate lever performance exists at 40 to 50 db, a threshold measurement on a mentally retarded child usually can be obtained in one 30-minute session. The easily observable criterion, of course, is whether the child immediately switches to the right lever when his previous responses have turned the tone on and then immediately switches to the left lever when his responses have turned the tone off. The nature of the ratio programming is such that coincidental switching from one lever to the other is very improbable.

Preliminary quantitative results obtained with mentally retarded children who were trained A. with all procedures as they were developed, B. after the lever-light procedure was developed and C. with the final procedure only are shown in Table 2. The effectiveness of the final procedure is obscured somewhat in the cases listed under A and B (Table 2) because the training they received earlier was incompatible with the training given later. In addition, no attempt was made to obtain absolute thresholds even with the final procedure because of the unduly high noise level in the testing room. Although only two cases were tested entirely with the final procedure and more cases would surely be desirable, the rapid and accurate performance that was demonstrated at near-threshold levels lends support to the belief that the procedure is effective. It is clear, for example, that subject JK (Table 2, C) has a hearing loss at 500 and 4000 cps in his right ear.

Table 3 shows the qualitative results on the cases in which measurement of threshold hearing was not attempted. It will be seen that difficulties were encountered with some subjects and with other subjects work was begun too late to be completed within the period of the contract with the Office of Education. Another group of subjects exhibited social and emotional behavior that prevented measurement, and the last group was not reinforceable by the available reinforcers. These data are presented here simply to indicate that not all children were amenable to the procedure. The frequency with which mentally retarded children are resistant to operant

Quantitative Operant Conditioning Findings for Cases in Which Measurement of Hearing Was Attempted

Subject	Sex	Initial CA	IQ*	Diagnosis	No. of Sessions	Lowest Intensity with Good Lever Performance — right ear 500	right ear 1K	right ear 2K	right ear 4K	left ear 500	left ear 1K	left ear 2K	left ear 4K	Experimenter's Comments
A. Cases Subjected to All Procedures														
NA	m	16	48	undifferentiated	10	30	30	30	30	30	30	30	30	Normal threshold probable after additional training.
AH	m	11	45	undifferentiated	9	10	10	10	10	20	20	20	20	Probably within normal range.
BK	m	15	35	brain damaged	7	20	20	20	35	20	15	15	50	Definite hearing loss.
DL	m	15	67	brain damaged	6	10	10	10	10	10	10	10	10	Within normal range.
BM	m	16	39	brain damaged	9	15	10	10	10	20	20	20	20	Probably within normal range.
JR	m	17	30-	brain damaged	10	60	60	60	50	25	30	30	30	More training desirable. Probably right ear loss.
CS	m	11	37	mongoloid	7	30	30	30	30	30	25	40	40	More training desirable. Probably left ear loss.
MT	f	16	48	brain damaged	9	15	15	15	15	15	15	15	15	Probably within normal range.
TT	m	16	30-	mongoloid	8	25	20	20	20	20	20	20	20	Probably within normal range.
DV	m	15	52w	undifferentiated	8	25	25	25	25	15	15	15	25	Probably within normal range.
B. Cases Tested Only after Lever Lights Procedure Developed														
JB	m	12	38	mongoloid	5	25	20	20	60	20	20	20	40	Definite loss.
JC	m	12	41	brain damaged	5	20	20	20	45	20	20	20	20	Definite loss.
PS	f	16	39	mongoloid	4	30	30	25	25	25	25	25	25	More training desirable. Probably within normal range.
JS	f	11	39	psychotic	5	20	20	20	20	20	20	20	20	Probably within normal range.
MW	m	8	56w	brain damaged	4	25	15	15	15	20	15	15	15	More training desirable. Probably within normal range.
C. Cases Tested Only with Final Procedure														
JH	m	12	34	microcephalic	2	20	15	20	25	20	20	20	20	Probably within normal range.
JK	f	17	41	mongoloid	2	30	20	20	50	20	20	20	25	Definite loss.

* IQ [Binet unless indicated Wechsler (w)] obtained within two years of first session.

TABLE 3

Qualitative Operant Conditioning Findings for Cases in Which Measurement of Hearing Was Not Attempted

Subject	Sex	Initial CA	S-B IQ	Diagnosis	No. of Sessions	Experimenter's Comments
A. Cases Needing Additional Training						
FB	m	16	33	undifferentiated	8	These subjects entered the project in its early stages. Positive response to the task and situation supported belief that measurement of hearing would be possible with further training. JD and JR, for example, shifted very slowly from light to tone control; DK required 3 sessions to shape proper earphone behavior.
JD	m	12	50	undifferentiated	4	
DK	f	13	30-	mongoloid	9	
DP	m	16	40	brain damaged	7	
JR	f	13	38	brain damaged	11	
JC	m	16	40	undifferentiated	3	These subjects were progressing through the training sequence with no difficulty but entered the project in its late stages and at the time the testing was terminated needed one or more further sessions.
MH	m	16	38	brain damaged	4	
TM	m	15	41	undifferentiated	3	
BS	f	6	*	mongoloid	2	
HS	m	16	49	brain damaged	3	
PW	m	5	*	mongoloid	1	
JW	m	19	30-	microcephalic	2	
B. Cases Showing Social and Emotional Behavior Incompatible with the Task						
DB	m	8	38	brain damaged	5	With the exception of TF, these cases were resistant to the laboratory and eager to return to school. TF engaged in constant psychotic-like imaginary play.
KC	f	16	33	brain damaged	5	
TF	m	17	41	mongoloid	5	
SP	f	11	24	microcephalic	6	
C. Cases Unreinforceable by Available Reinforcers						
LC	f	17-	30-	brain damaged	2	These subjects pulled the lever on instruction but did not pick up or show interest in the reinforcers.
WK	m	13	30-	brain damaged	2	

* untestable

conditioning procedures for the measurement of hearing was not studied in this research. An extensive try-out of the procedure at a speech and hearing center or a school for the mentally retarded, where large samples of children are readily available, would be desirable.

Summary. A procedure was developed for measuring the pure tone hearing thresholds of difficult to test, mentally retarded children that was automatic except for the changing of the frequency and intensity of the stimulus. Three 30-minute sessions were sufficient to obtain threshold measurements in a few cases that were tested after experience had been gained with the procedure. The first session brought the discriminative pulling of the right or the left lever under the control of light and sound stimuli. The second session brought the discrimination under the control of the sound stimulus alone and introduced generalization training to all frequencies. The third session extended the generalization training and reduced the loudness of the stimulus to threshold levels. Observation of the intensity levels where a child's previously accurate discrimination broke down provided a simple measure of his hearing threshold for that frequency.

Automatic Procedures with Mentally Retarded Children:

Technical Description

Initial Procedure. A 500 cycle tone of about 40 db (re audiometer zero) from the loudspeaker was turned on. After a brief period of continuous reinforcement on the right lever, a variable ratio (VR) was gradually introduced until the performance seemed fairly steady.

The tone was turned off, and the left lever was programmed to provide reinforcement. If a child didn't try the left lever as a function of extinction on the right one, the experimenter entered the room and demonstrated the effectiveness of the left lever. After a brief period of continuous reinforcement, a gradually progressive VR was introduced.

The left lever was programmed to turn on the tone instead of providing trinket reinforcement. At this time, also, the VR on both levers was reduced to about 4 to compensate for the decreasing frequency of trinket reinforcement.

As in Blough's procedure, the tone went off after trinket reinforcement, but not after every trinket reinforcement. Sometimes the tone remained on, and another trinket could be obtained by operating the right lever. Whereas Blough changed the stimulus after four-fifths of the reinforcement deliveries, this more variable schedule permitted two or three reinforcements before the tone went off.

It was originally planned to introduce the response control of the tone intensity after good tone control of the responding had developed and at the same time introduce the interval timer, such as Blough used, which would precede the ratio contingencies. This perhaps could have been done with a few children who demonstrated good tone control in one or two sessions, but there was considerable difficulty with others. One difficulty stemmed from the fact that unless tone control developed rapidly, the child made many responses without reinforcement and eventually left the testing room.

Another difficulty developed from the tendency of a variable ratio schedule to differentially reinforce very rapid, and therefore effortful, kinds of responding. This response mode seemed to exaggerate the emotional effects normally resulting from extinction and also increased the likelihood that the child would leave the room. To prevent such a response

mode from ever being reinforced, a temporal contingency was added to the variable ratio schedule. Any response that followed the preceding one by less than .3 second did not count toward the required ratio. "Less than .3 second" was made the criterion because observation indicated that .3 second seemed a little too long and .2 second a little too short. It will be recognized that this is a contingency for differential reinforcement of low rates (drl).

There are several ways in which drl can be made to precede a VR, but unless it precedes every response that enters the count programmer, the ratio is greatly increased or distinctive bursts and pauses develop. Once the described drl-VR was added, however, no more difficulty with rapid response modes was encountered. The typical pattern was relatively steady responding at such a rate that most of the responses counted toward the ratio. It should be noted that the VR, on the left lever at least, should be quite variable and should contain a few very long ratios. If this is not provided for, switching levers becomes increasingly likely as responses continue to occur without a stimulus change.

The Lever-Light Procedure. Decreasing the effortful rapid responding helped to prolong the child's stay in the room, but the discrimination was too difficult for the rapid development that was desired. To make the discrimination easier, a visual stimulus with obvious spatial relation to the levers was correlated with the auditory stimulus, and then the visual stimulus was gradually removed.

Learning to pull whichever lever was under the illuminated light panel (cf. Figure 1b) proved to be very easy, and the rest of the program remained the same as described above: drl-VR on each lever first for trinkets, then on the left lever for the production of the tone and (with the addition of the lights) for the offset of the left lever light and the onset of the right lever light.

As one might expect from the close spatial relation between the lights and levers, this stimulus control was invariably dominant at first. However, gradually fading the lights resulted in a gradual shift from light to tone control without the necessity of any prolonged extinction. With this new procedure, a fair tone discrimination usually could be developed in two to five half-hour sessions.

At this phase of the research, it was planned to insert a variable interval timer in the schedule and to introduce response control of the tone intensity.

However, for this means of measuring thresholds it is important that erroneous responses (whether they consist in continuing to pull a lever when the stimulus condition has changed or in switching levers before the stimulus has changed) occur infrequently except as threshold is approached, and it is important that they occur about as often on one lever as on the other. If there are numerous errors or if they are unequally distributed on the two levers, the threshold will be unreliably measured.

The fading lever-light method made the discrimination much easier, but great difficulty was still encountered with some children in eliminating errors. This difficulty probably resulted because a good deal of reinforcement can be obtained even with a relatively unprecise discrimination. Accordingly, the interval schedule and the response control of the tone intensity were again postponed until this problem could be overcome.

Blough used several contingencies to increase the precision of the stimulus control, but all of them involved extinction or punishment and such control was difficult or impossible to impose in our situation. A modification of one of Blough's "punishment" contingencies was used, however: namely, causing errors to add to the number of responses yet to be completed on the correct lever. Each erroneous response added one to the next ratio to be completed when correct responding was resumed, except that the ratio could never be increased by more than 5. This contingency functioned mainly to prevent rapid alternation or simultaneous response on both levers from ever being reinforced.

One of the most common errors made by subjects was in returning to the right lever after reinforcement when the tone was off and the left lever should have been pulled to turn the tone on again. Observation through the one-way mirror revealed a rather obvious cause for it. As the schedule was programmed during this phase of the work, the tone went on as a function of responding on the left lever, but it went off at the end of the reinforcement-tray illumination cycle which lasted about 1.5 seconds. This meant that in many cases the child was picking up and examining the reinforcer at the time the tone went off, and if he did anything with it other than to place it in his bag, the tone had been off for a second or two when he resumed responding. To respond to a stimulus change is much easier than to respond to a static stimulus condition as could be deduced from the fact that even an unprecise discriminator seldom failed to switch from the left to the right lever when the response

on the left lever turned on the tone. In brief, examination of the reinforcer prevented response to the tone turning off, and responding to the tone being off is a more difficult discrimination. This interpretation of the error was strengthened by the effects of inserting a variable interval into the schedule to build up a persistent switching back and forth between the levers even though no trinket deliveries occurred. During this interval the tone offset replaced the reinforcement cycle on the right lever, and errors on the right lever often ceased. This finding could have been considered encouragement to ignore this type of error since it was less likely to occur during threshold measurement. However, its occurrence during the early phases of the development of tone discrimination seemed to delay the training by as much as a whole session or more.

Early experience with response control of the tone intensity was discouraging. Only a few threshold crossings at a time seemed possible since these crossings inevitably involved responding without receiving any trinkets. Also, in view of the relatively unprecise discriminative performance, it appeared that reliable threshold measurement would require considerable further training of our subjects.

These considerations led to a reevaluation of a response-controlled, tone intensity procedure, using the Blough-Bekesy approach, as an ultimate goal. It was quite clear in the experimental work that an observer watching a fairly well trained subject could determine with almost no chance of error whether the subject was responding to the tone or not. The nature of the variable ratio schedule for tone onset is such that a coincidental switch to the right lever at the moment of the tone onset is quite unlikely. Two or at most three, positive instances suffice to render coincidence virtually impossible.

It was also quite clear that the observer could reduce the tone intensity by 10 db or so while the tone was off, and when it came on again at the lower intensity the subject was relatively unaffected by the change. This observation led to altering the schedule so that stimulus offset as well as stimulus onset resulted from the subject's response, and since the program was no longer regarded as preliminary training for response intensity control, trinket reinforcement was provided on the left lever as well as on the right lever.

Final Procedure. Beginning with the tone off, responding on the left lever could produce a trinket on drl-VR 8 or could turn on the tone. If the tone was on, responding on the right lever could produce a trinket or turn the tone off. On the average, one or two trinkets were delivered before the stimulus change was produced, although occasionally as many as three trinkets would be delivered. The schedule on the left lever was exactly the same as on the right lever except with respect to whether switching was controlled by tone off or tone on.

One additional change in the schedule facilitated measurement in the final procedure. It was observed that a few subjects did not switch levers promptly when the stimulus condition changed. Instead, they slowed down gradually, usually making from three to seven erroneous responses before they switched to the correct lever. This process was especially characteristic of subjects whose overall rate was low. The tone control was quite clear, but threshold measurements were less reliable because it was difficult to distinguish this mode of switching from coincidental erroneous switching. Accurate measurement would require prolonged responding at near threshold intensities, and this was considered undesirable.

The problem was eliminated by providing a reinforcement for the first response after switching levers if the switching occurred promptly. "Promptness" was programmed in the beginning as three seconds and gradually decreased to one-half of a second. This contingency can be described as a bonus for quick switching inasmuch as the subject obtains a reinforcer without having to complete the required ratio of responses. The bonus should be given only for approximately every third quick switch, however, or the response of switching itself becomes so strong that frequent erroneous switching reappears.

When performance was fairly adequate and the subject had experience in responding to the several tone frequencies, threshold measurement could be accomplished in 10 to 20 minutes. The observer simply reduced the intensity in 5 to 10 db steps and recorded the point at which accurate switching was lost. Both onset and offset observations were useful, and several descending approaches to threshold were usually made before the frequency was changed. Ascending measurements were not used since the subject would be on extinction or chance responding until the threshold was reached, and this did not seem advisable. The procedure, as described, does not involve any extinction during threshold measurements nor any change in procedure. The subject at the critical trials simply does what he has always been doing except that for brief periods the tone becomes weaker.

Technical Summary of the Final Procedure

Introductory Procedure. In some cases the basic schedule can be introduced immediately. More frequently, continuous reinforcement gradually working up to the VR 8 is desirable.

Basic Schedule. Trinket and tidbit reinforcement is given on a VR 8 schedule with responses counted for the ratio only if there is a .3 second pause between them. Sometimes the second reinforcement, but more often the third and always the fourth reinforcement is replaced by a change in the stimulus conditions. When the right lever light and the tone are "on", the basic schedule prevails on the right lever and no reinforcement is given for responding on the left lever. When the left lever light is "on" and the tone is "off", the basic schedule prevails on the left lever, and no reinforcement is given for responding on the right lever.

Testing of Individual Ears. Earphones are placed on the subject as soon as he will accept them. While initial training on the basic schedule can be given binaurally, monaural listening with systematic change from ear to ear is desirable.

Error Effects. Erroneous responses add one to the ratio yet to be completed on the correct lever, but no more than five are added in any one run of errors.

Bonus Reinforcement. A bonus reinforcement, delivered on a variable basis, is available for one-third of the correct lever switches that are made "promptly." Initially the bonus is given for a correct switch of levers made within three seconds after the stimulus condition changes. The time permitted is gradually reduced to one-half second.

Change of Frequency. The frequency of the pure tone is systematically varied so as to provide listening and discrimination training on all of the frequencies for which thresholds are desired.

Removal of Light Stimulus. When performance is adequate, the light stimulus correlated with the levers is gradually faded at a rate that avoids prolonged extinction. Discrimination comes to be based entirely on the sound stimulus.

Threshold Measurement. Thresholds are measured by reducing the intensity of the stimulus in 5 to 10 db steps, from a point well above threshold, for each frequency and each ear. A sudden change from correct to incorrect responding identifies the descending threshold.

Care must be taken to approach the threshold several times rather than to require long periods of responding at near threshold levels.

Comparability of Operant Conditioning and Standard Audiometric Results

Four normal adults, four normal children and five deaf children were tested with the same audiometer, first by a standard audiometric technique and then by a single, 30-minute operant conditioning session. Testing was done on a school holiday when the laboratory was unusually quiet. The results are shown in Table 4.

It will be seen that the threshold obtained by the two methods are reasonably comparable. On the average, slightly lower thresholds were obtained by the standard method, especially among the adults who found the trinkets less reinforcing than did the children. Among the normal children, approximately three-fourths of the separate thresholds obtained by the two methods were within 5 db of each other and 94 percent of the thresholds were within 10 db of each other. An additional 30-minute session with the operant conditioning apparatus undoubtedly would have reduced the differences even further.

Possible Improvement of the Apparatus and the Automatic Procedure

Four aspects of the final procedure were not automatic but required intervention by the observer. These were switching the tone from one frequency to another and from one earphone to the other, and attenuating the intensity of the light and the tone. It seems possible, however, to make the procedure entirely automatic so that the training and testing of individuals and groups could be undertaken with only normal supervision by an observer.

TABLE 4

Comparison of Thresholds Obtained with the Same Audiometer Using a Standard Audiometric Method (a) and a Two Lever Discrimination Procedure (b)

Subject	Procedure	Thresholds right ear 250*	500	1K	2K	4K	left ear 250*	500	1K	2K	4K
A. Normal Adult Subjects											
JB	(a)		5	0	0	5		15	5	5	10
	(b)		10	10	10	10		10	10	10	10
PF	(a)		0	-5	-10	-10		10	5	0	0
	(b)		5	5	5	5		5	5	5	5
DG	(a)		0	0	15	5		0	5	10	10
	(b)		15	15	15	15		15	15	15	15
IM	(a)		5	0	-5	0		5	5	5	-10
	(b)		0	0	0	0		0	10	5	0
B. Normal Children											
MD	(a)		10	5	5	0		10	5	5	0
	(b)		5	5	5	5		0	5	5	5
TJ	(a)		35	30	10	5		10	15	5	10
	(b)		35	35	15	15		10	20	10	20
BT	(a)		10	5	5	0		0	-5	-10	0
	(b)		0	0	5	0		0	0	0	10
LT	(a)		5	15	15	20		5	0	0	0
	(b)		15	10	15	15		10	15	15	10
C. Children with Severe Hearing Loss											
BW	(a)	-	90	100	-	-	-	90	-	100	-
	(b)	-	95	100	-	-	-	100	100	-	-
LM	(a)	-	90	-	-	100	-	85	100	-	-
	(b)	-	100	90	-	-	-	90	95	100	-
DJ	(a)	75	75	95	-	-	70	75	95	-	-
	(b)	65	80	95	-	-	75	80	95	-	-
JW	(a)	-	75	95	100	-	-	80	100	-	-
	(b)	gave indication of hearing tone but could not get discriminative lever performance									
MK	(a)	70	80	100	-	-	75	95	100	-	-
	(b)	gave indication of hearing tone but could not get discriminative lever performance									

* used only for children with severe hearing loss

Apparatus for the automatic switching of tones from frequency to frequency and from one earphone to the other is commercially available and requires only money to obtain. Bringing the attenuation of the light and the tone under automatic control, under conditions acceptable to mentally retarded children, is more difficult. However, an untried but plausible technique for automatic intensity adjustment probably could be added to the final procedure without changing it in other respects.

In the final procedure, the observer attempted to attenuate the intensity of the stimulus as rapidly as possible without causing a breakdown in the discriminative performance. His criteria for discriminative breakdown were primarily an increase in incorrect responding or a decrease in overall rate of responding although, of course, he made use of more subtle cues such as facial expression and vocalization. When errors increased or rate decreased, the observer increased the intensity of the stimulus.

To replace the observer, therefore, it would be necessary only to let some recordable criteria of discrimination adequacy automatically control first the light intensity and later the tone intensity with a procedure such as the following:

Two electronic timers, two stepping switches and a double-throw relay are required. Timer 1 is reset to zero by a response. It operates continuously so long as the subject makes a response to either the right lever or the left lever within 10 seconds. If the subject makes no response in 10 seconds, as often happens when a discrimination becomes difficult,

Timer 1 turns off and remains off until the next response is made. Timer 2 operates as long as the first timer is operating, but it stops and resets to zero if Timer 1 stops. When it is operating, Timer 2 recycles every 20 seconds and sends out an electrical impulse at the end of each cycle. This interlocking arrangement of the two timers prevents the stimulus intensity from being changed unless the subject is responding.

Stepping Switch 1 is wired so that each incorrect response steps it up one position to a maximum of ten steps. When Timer 2 is operating, the electrical impulse that it sends out at the end of each cycle serves two functions: First, the pulse resets Stepping Switch 1 to zero. Second, the impulse simultaneously goes to the relay contact and depending on the open or closed state of the relay it decreases or increases the intensity of the stimulus via Stepping Switch 2. The state of the relay is determined by the position of Stepping Switch 1 which is responsive to errors. If 10 errors have been made in 20 seconds and Stepping Switch 1 is at position 10, the relay is closed and Stepping Switch 2 operates to increase the intensity of the stimulus. If less than 10 errors have been made in 20 seconds, the relay is open and Stepping Switch 2 operates to decrease the intensity of the stimulus.

In practice, the apparatus would operate as follows: If the subject paused for 10 seconds or longer, the stimulus intensity would remain unchanged. If the subject made less than 10 errors in 20 seconds the stimulus intensity would be automatically decreased. If the subject made 10 errors or more in 20 seconds the stimulus intensity would be automatically increased.

The time and error limits, of course, have been selected simply for illustration. Optimal limits for subjects varying in age or disability would have to be determined empirically. It should be mentioned, too, that the increase and decrease of stimulus intensity need not necessarily be symmetrical. It would be desirable, in fact, that increases in intensity after the error limits had been exceeded should be greater than the decreases in intensity after adequate performance. In this way, when performance broke down at or near threshold intensities, the stimulus would be increased to a point well above threshold before the threshold was approached again. Repeated cycles of this kind on different frequencies, it is believed, would allow automatically controlled threshold measurements to be made repeatedly without inducing the excessive strain that often follows when a subject is required to respond for long periods of time at or near threshold intensities.

DISCUSSION

The final procedure developed by this research, and the observations leading to its possible further improvement, are considerably removed from the slight adaptations of the Blough procedure that were anticipated when the work was begun.

Of course, the development work still must be considered only preliminary and undoubtedly numerous other approaches are possible in general and in detail. We have neither described all of the unproductive leads encountered in this research nor mentioned the numerous possibilities for further work. For example, it would be of interest to determine the effects of using silence rather than sound as the discriminative stimulus. It would be possible, and perhaps of value in evaluating multiply handicapped blind children, to substitute a slight vibration of the correct lever instead of the initial discrimination to the light stimuli. Alternatively, silence, light and vibration could be dispensed with and sound stimuli alone arranged with the same natural spatiality that existed for the initial light stimuli; i.e. a tone in the right earphone would be correlated with the right lever and a tone in the left earphone with the left lever. We have speculated upon the effects of these procedures and their possible values in evaluating or training exceptional children, but we have not explored them. However, the following gains have been made.

1. A method has been devised for measuring hearing thresholds which, it is believed, may have value for several populations and several purposes. For example, it can be used

routinely with children and adults when, for any reason, the face-to-face procedure of standard audiometry is not desirable.

2. The method is of special value in cases that are "hard to test" because of problems presented by immaturity, speech or language difficulties, disinterest in the usual audiometric procedures, mental retardation or brain damage.

3. The method has value also for preliminary sensitization and discrimination training which will prepare "hard to test" cases for later threshold measurement by regular audiometry. For example, if the apparatus described were standard equipment in speech and hearing centers, it would not be necessary to dismiss a child who appeared to be unresponsive to sound with vague instructions to the parents to try to sensitize him to sound or to bring him back for another test when he was older.

4. The method offers a new approach to problems of differential diagnosis when the possibilities are mental retardation, impaired hearing, language retardation, aphasia, psychosis or a combination of these. For example, several of our subjects were described as "functionally" mentally retarded and they were being educated in a school for the trainable mentally retarded. The speed, accuracy and flexibility of their performance on the operant conditioning apparatus, however, was clearly as good as the performance of normal children and markedly different from the performance of most of the mentally retarded children.

Similarly, it seems reasonable that if a child is able to learn a discrimination to light and vibratory stimuli but not to sound stimuli, or if the patterns of acquisition of the

discriminations are divergent, considerable light may be cast upon the nature of the impairment. The present investigation was not well adapted to the study of this problem inasmuch as the tone discrimination task was more difficult than the light discrimination. A single light source varying in brightness would appear to be more comparable to tone stimuli. Nevertheless, these kinds of problems appear to be ripe for investigation.

5. The method permits a new and convenient approach to the observation of mentally retarded children which may throw light upon some characteristics of this defect and contribute to a more rational scheme of classification.

Although the main purpose of this research was directed toward the measurement of auditory thresholds in the retarded, it is evident that the same procedure can be used to study visual thresholds and visual skills also; and only slight adaptation would be required to allow the study of form perception or space perception. In addition the experimental situation offers an excellent opportunity to observe the behavior of exceptional children as it is influenced by tasks of varying difficulty, differing schedules of reinforcement, the presence or absence of other children or adults, and other variables.

After evaluating the work with the mentally retarded children, the conclusion was inescapable that the conventional classifications of different kinds and degrees of retardation were not closely related to the rapidity with which a child could develop a complex discriminative performance. Individual differences within diagnostic or I.Q.-level groups were far greater than the

differences between groups, but the nature of the variables that account for good discrimination were not clear. Data obtained, but not reported in this paper, indicate that successful predictions of performance in discriminating auditory and visual stimuli that are well above threshold cannot be made from knowledge of diagnostic classification or I.Q.

6. The method may be adapted to improve the behavior of mentally retarded children. For example, one 7-year-old child, who was spoon-fed by his mother, was reported not to "like" anything. If left to himself he would sit quietly in a corner. It was discovered that he was responsive to rock and roll music, and in a relatively short time he was "hand-shaped" into eating candy using music as a reinforcer. Later, he pulled the levers of the operant conditioning apparatus to get candy to eat, to listen to music. Ultimately, he pulled the levers for food reinforcement alone which he ate with apparent enjoyment.

The initial stage of this work was begun while the mother of the child was observing from the observation room. She was so excited by it that she asked if she might run and bring her husband to watch too for it was the first time, she said, that the child had ever engaged in a purposeful act.

Similarly, one mentally retarded subject, who might be described as a "human vegetable" was found to be responsive to vibration, and using this stimulation as a reinforcer it was possible to shape-up the beginnings of some non-random motor activity.

This kind of investigation, too, deserves much further research.

7. The method is adaptable to the study of some general problems of child psychology such as the development and maintenance of "motivation", superstitious behavior and work habits. For example, a normal nursery school child was a source of concern to his teachers because he did not like to draw and color, and there was considerable speculation about the nature of his deep-seated emotional problems. The child was given trinket reinforcement contingent upon engaging in drawing and coloring behavior in the laboratory. The behavior was readily conditioned and appeared to carry over to the nursery school environment.

8. The method may have value in training parents and teachers in principles which lead to the effective control and guidance of children's behavior. Several mothers, watching from the observation room, were impressed with the ease with which temper tantrums could be extinguished. Others began to see that it was not necessary to spoon-feed their children with baby food.

9. The method may lead to observation of unusual behavior or to speculations that are worthy of investigation.

A deaf child showed recruitment of hearing in high degree. On standard testing a tone was audible only within a range of a few decibels. Below that level it appeared to be inaudible. Above that range the child clapped her hands over the earphone, screamed and indicated discomfort or pain. On the operant conditioning apparatus, this behavior quickly extinguished and the child showed no discomfort at intensities that previously had aroused pain reactions.

2

An epileptic, retarded child, kept under heavy sedation for the control of seizures, frequently fell asleep in the testing room. At rare intervals when she was fairly alert, it was evident that although her repertoire of behavior was extremely limited, she could learn. It would be of interest to have an empirical test of the relative long-term advantages of different degrees of sedation in cases like this. Heavy sedation controlled the seizures and thereby, it was believed, prevented further brain damage; but it also deprived the child of opportunities to learn. Milder sedation might allow some seizures to occur, but they might be less harmful in the long run than expected, and the child's zombie-like existence might be ameliorated. Performance on the operant conditioning apparatus over a period of time could serve as one measure of gain or deterioration.

10. Two by-products of the research were an improved connector for wiring behavioral research apparatus, which allows more than one program to be set up without rewiring, and a device for loading a reinforcement feeder automatically. These designs have been communicated to a manufacturer of behavioral equipment.

SUMMARY

The problem of this research was to devise a new, non-verbal and non-language procedure for testing the hearing of mentally retarded children in which impairment in discriminating pure tones at threshold levels would not be confused with impairment of auditory sensitivity.

The research developed from the following hypotheses: 1. The reported high incidence of impaired hearing for pure-tones in mentally retarded children is an artifact of the method of measurement. 2. Operant conditioning procedures that have proved successful in obtaining very sensitive measures of visual threshold in the pigeon can be adapted successfully to provide valid and reliable measurements of hearing thresholds in mentally retarded children.

Starting from operant conditioning procedures described by other investigators, the following new procedure was developed. A subject was seated, in a sound-treated room in front of a panel equipped with a lever on the right and a lever on the left, a stimulus light panel above each lever, a feeder tray, and plug-in connections for earphones. An intercom and a loud-speaker were attached to opposite corners of the ceiling above the panel. An adjoining observation room, containing an audiometer, recording attenuator, intercom master controls and a switch console connected to behavioral research programming and recording equipment in the control room, allowed the experimenter to control the apparatus while observing the subject through a one-way vision mirror.

The panel light above the right lever was lit when the child entered the experimental room, and the panel above the left lever was dark. Earphones delivering a 500 cycle tone at 40 db (re audiometer zero) were placed over his ears if he would accept them; otherwise the tone was channeled temporarily to the loudspeaker mounted on the ceiling. When the child pulled the lever on the right under the illuminated panel, a trinket was dispensed into the feeding tray, the panel above the left lever became illuminated, while the panel above the right lever went dark, and the sound stimulus ceased. Pulling the lever under the now illuminated left panel and in the absence of the sound stimulus resulted in trinket reinforcement, the switching of the illumination to the right panel, and the onset of the sound stimulus. Thereafter, each panel light remained on for a variable period of time until the child learned that pulling the lever below the illuminated panel paid off in trinkets while pulling the lever below the dark panel did not. To facilitate the perception of the reinforcer, a light went on momentarily in the trinket feeding tray, simultaneously with the delivery of every trinket, and the overhead laboratory light momentarily dimmed. During this period and subsequently, the sound stimulus was "on" only when the right panel was illuminated.

The program was scheduled so that the subject received from one to three separate reinforcements, on a low variable ratio schedule, for pulling the lever below the illuminated panel, and then his own further responding, automatically caused the electronic programmer to switch the illumination to the panel

above the other lever, but no trinket reinforcement was given at the time the switching of the stimulus occurred. Stable performance for this discrimination was usually achieved in one 30-minute session.

In the following session, the observer gradually decreased the illumination of the panel lights to zero so that the lever pulling was brought completely under the control of the tone: when the tone was "on", the right lever paid off and when the tone was "off" the left lever paid off in trinket and candy reinforcements. Tones of different frequency were presented in sequence. Stable performance for this discrimination was usually achieved in one 30-minute session.

In the final session the frequency of the sound stimulus was systematically rotated several times among tones of 500, 1000, 2000, and 4000 cycles. When discrimination was well established for all frequencies at levels well above threshold, the intensity of the tone was decreased in 5 or 10 db steps while changing from frequency to frequency. If generalization training was adequate, and accurate lever performance existed at above threshold levels, a threshold measurement on a mentally retarded child could be obtained in one 30-minute session. The easily observable criterion was whether the child immediately switched to the right lever when his previous responses turned on the tone and then immediately switched to the left lever when his responses turned off the tone.

Technical aspects of the procedure were described in detail in the body of the report.

The results obtained, after experimentation with 67 mentally retarded children lent support to the belief that the procedure was an effective one, although not all subjects were amenable to it.

A comparison of the thresholds obtained on 13 non-retarded subjects using a standard audiometric method and the operant conditioning procedure indicated that the results obtained by the two methods were comparable.

An extensive try-out of the operant conditioning procedure would be desirable at a speech and hearing center or a school for the mentally retarded where large samples of children are readily available.

Four aspects of the procedure used were not automatic but required the intervention of an observer. It appeared possible, however, to make the procedure entirely automatic so that the testing and training of individuals or groups could be undertaken with only nominal supervision by an observer, and a plausible technique for accomplishing this was described. Apparatus specially constructed for further experimentation is expected to be commercially available by January, 1961.

Development of operant conditioning procedures for evaluating and training exceptional children is still in its early stages. Undoubtedly many approaches are possible. Some interesting observations made during the course of the research and some of the possibilities, not only for measuring hearing thresholds but also for numerous other kinds of investigations, were mentioned.

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